Executive Summary

This paper documents the findings of the March 12-14, 2001 **Workshop on New Visions for Large-Scale Networks: Research and Applications**. The workshop's objectives were to develop a vision for the future of networking (10 to 20 years out) and to identify needed Federal networking research to enable that vision. The meeting was sponsored by the Large Scale Networking Coordinating Group (LSN CG) of the Interagency Working Group in Information Technology Research and Development (IWG/IT R&D). The IWG, which functions under the White House National Science and Technology Council, coordinates Federal multiagency IT R&D efforts. The LSN CG agencies are DARPA, DOE, NASA, NIH, NIST, and NSF. The Network Research Team (NRT) of the LSN CG coordinated the workshop. It was attended by more than 160 leading networking researchers from universities, industry, government, and laboratories.

The participants concluded that industry is not prepared to do the long-term research needed to enable the workshop visions for future networking. Industry is oriented toward near-term development and is currently scaling back the corporate ability to provide networking research. This places increased responsibility on Federal agencies to fund and conduct the research needed to support the continuing growth of the Internet.

The workshop organizers developed scenarios of visionary uses of the Internet, including:

- **Zero-Casualty War**: The intelligent, automated, densely sensored battlefield
- **Smart World**: Intelligent, aware, secure embedded sensors for maintaining battlefield systems
- **Crisis Management**: On-line emergency resources supported by distributed sensors, dynamic networking, and distributed high-performance modeling
- **Collaboratories**: Proactive, intelligent, dynamic, "natural" interactions
- **Networked Medical Care**: Distributed medical services through collaboration with high security, high assurance, and guaranteed Quality of Service (QoS)
- **High-Energy Physics**: Collaboration with high-end, on-line resources

Discussion in workshop breakout sessions identified networking research needed over the next five years to enable these visions. These research needs include:

- **Adaptive, dynamic, and smart networking**: Networks in the future will need to be intelligent and able to adapt to dynamic and evolving situations. They will need to be self-organizing, dynamic, and responsive to applications, to support application responsiveness to networks, and to provide automated network management and QoS.
- **Measurement, simulation, modeling, and scalability**: Scalable networking technologies are critically needed to support projected massive increases in nodes, traffic, users, and complexity of the Internet. Simulation, modeling, and standardized end-to-end performance measurement are needed to support development of new technologies, standards, and network management. A long-term archive of continuous performance measurements is needed to support retrospective studies and trends analysis.

- **Trust (security, privacy, and reliability)**: Security, privacy, and reliability are ubiquitously needed to provide user trust in using the Internet and in the information provided, and to protect sensitive information transported over the network.
- **Networking applications**: The workshop participants found great merit in the visionary scenarios developed for the workshop and in additional applications identified during their discussions. Significant networking research is needed to vertically integrate applications and to provide the tools and services needed to support the applications.
- **Middleware**: Middleware assures that distributed resources and applications work in a transparent and synchronized manner to provide end user services such as seamless transport of information in a trustworthy framework and functionality across heterogeneous network elements to meet user requirements. The Grid (a high-end scientific, distributed, modeling infrastructure) developed with IT R&D funding, is an example of a developing middleware capability that needs to be extended through network research.
- **Testbeds**: Testbeds are needed to support networking research in performance measurement, security, privacy, reliability, active networking, adaptive mobile networks, intelligent networking, applications, and middleware. They are also needed to bridge the transition from the research stage to successful commercialization of technologies. Industrial participation is critical in developing and refining standards to provide technologies capable of near-term development by industry.
- **Collaboration environments**: Collaborative environments need to support transparent, intuitive human interactions with such services as automatic configuration, ubiquitous access, security, multimedia capabilities, immersive environments, expert consultation, and side conversations.
- **Revolutionary research**: With many orders of magnitude increases expected in the scale of the Internet, basic research is needed to understand network behavior and to study the complexity of networked systems. Research is needed to adapt relevant science from other fields such as chaos theory, stochastic processes, economics, catastrophe theory, and generalized control theory to understand networked systems' complexity and to address network modeling for scalability.
- **Revisit networking fundamentals**: In the future, network services and their associated protocols will need to extend across heterogeneous access technologies with seamless functionality. Fundamental changes may be needed in addressing, routing, forwarding, and transport modes to support the increased scale and functionality of the network. Research is needed to address basic issues in complexity, performance, and technology evolution/revolution.

Workshop participants emphasized the importance of networking research as a critical foundation for continuing the information technology revolution we are experiencing and for realizing their compelling visions of future networking. The workshop findings provide the LSN CG and LSN agencies with expert guidance from a wide range of private sector and government experts on Federal networking research needed in FY 2002-2006 and beyond to enable those visions of future networking.